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Alternate #

SUBJECT

COMMENTS ON SOFIA AIR COMPRESSOR REQUIREMENTS & ZEISS PHASE B
CONCEPT

PROJECT SOFIA

DISTRIBUTION

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AIR COMPRESSOR REQUIREMENTS AND
ZEISS PHASE B CONCEPT (NASA. Ames
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COMMENTS ON SOFIA AIR COMPRESSOR REQUIREMENTS &
ZEISS PHASE B CONCEPT

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April 2, 1990

COMMENTS ON SOFIA AIR COMPRESSOR REQUIREMENTS

This report reviews the compressed air system for the SOFIA air bearing as proposed by Zeiss. The Zeiss design is, of course, preliminary in nature and some suggested refinements are presented here. The air bearing pads have not been considered. It is assumed that the loads and airflow requirements for them are as stated in the Telescope Assembly Definition Phase B Final Report. Appendix A gives the calculations referenced below, and Appendix B gives a data sheet for representative dryers (those used on the Kuiper) and filters.

ZEISS SYSTEM

The system proposed by Zeiss is shown in Fig. 1 (Vol. II/3 Sect. 4.2.2.2 Pg. 31 of the Telescope Assembly Definition Phase B Final Report). The basic compressor system requirements either stated or inferred from this report are listed below:

Pressure.....	20 bar
Temp. (at aftercooler exit).....	270 K
Flow Rate.....	0.013 kg/sec
Accumulator Size.....	180 liters
Dew Point.....	Not Stated
Particulate Filter Requirement.....	Not Stated
Oil Content in the Air.....	Not Stated
Power Required	
Compressors/Coolers.....	12 kw
Heaters.....	1 kw
Total.....	13 kw

The air temperature entering the air bearing pads is controlled such that the air bearing is maintained at 215 K, ie. at or below the cavity temperature. A vacuum pump is utilized to recover the air and recycle it back through the system. Refrigerators (apparently) are used to cool the air upon discharge from the compressors in order to achieve the desired thermal cycle (as well as to help dry the air). After the final compression and drying the air is then adiabatically expanded to lower the temperature of the stream, with subsequent heating, so that the air bearing can be operated at 215 K.

Potential Problems

Moisture in the air presents some potential problems for this system. When the system is up and operating in flight moisture is not a concern since the system is recycling dry air (there is one caveat to this noted later). However, when the system is first started, problems could arise. It will take approximately 5.6 min to charge the accumulator from 1 atm. to 20 bar, plus another .2 min to charge the remainder of the system (see Appendix A, p5.

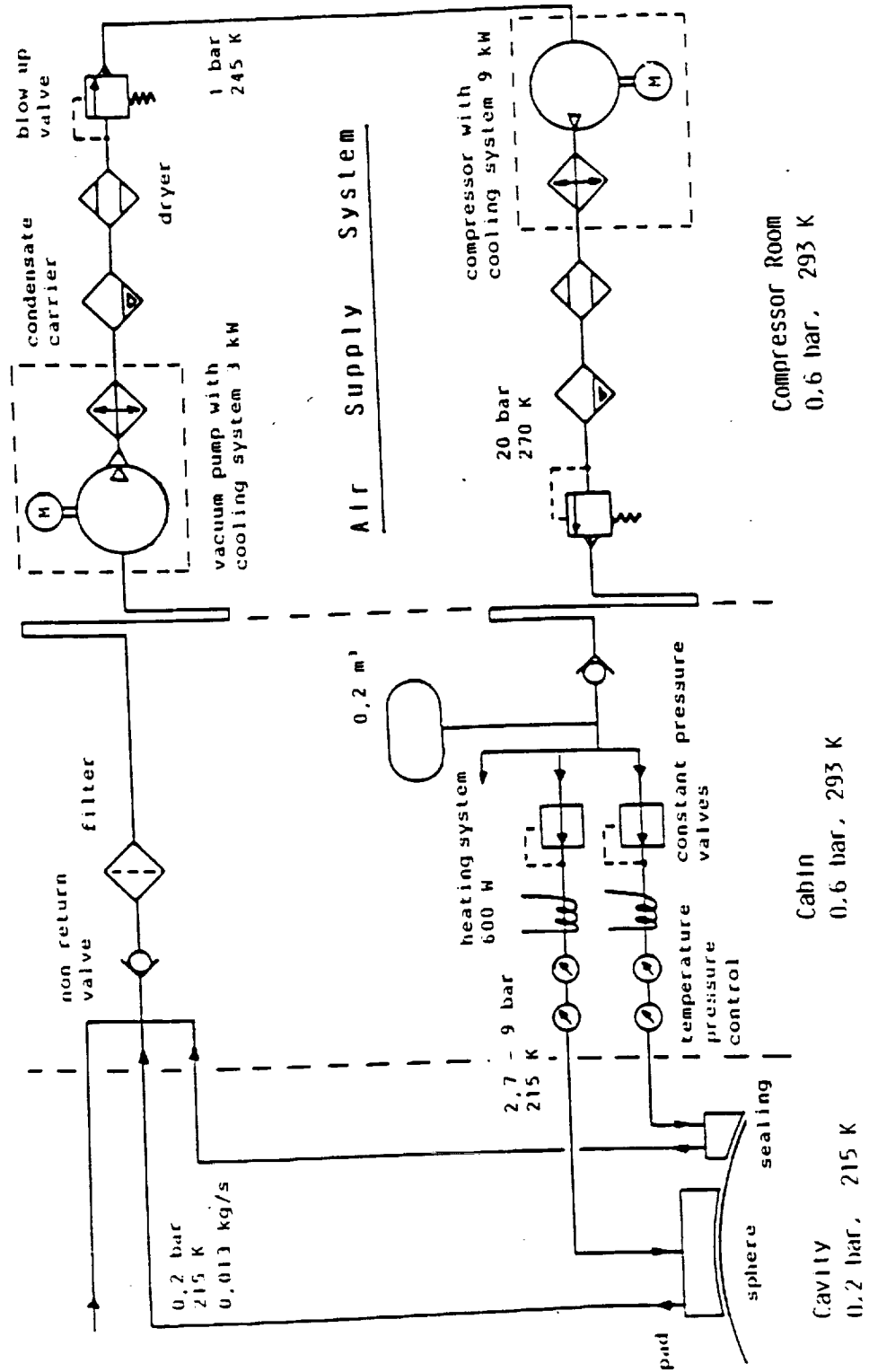


FIG 1

A1). During this time no air is being recycled. Instead, air is being drawn in from the outside.

The worst case start-up scenario would be a hot, humid day in the tropics. SOF 1010.01 defines a worst case of 100 F and 95% relative humidity. Under these conditions, drawing air in through the air bearing pad/seal return lines with the vacuum pump would cause condensation in the gap between the pads and the air bearing (pp. A2 - A4). (It should not be assumed that the cavity will be precooled, and therefore relatively dry, every time the compressors are started). To avoid this problem there is a make up air line which takes in cavity air and bypasses the bearing/seal pads. However, water will most likely condense in this line also. Care should be taken in the design of the bypass line to ensure that 1) no air is drawn in through the pad gaps, 2) in normal operation a minimum of air is drawn in through the bypass line and 3) any water that condenses in this line does not freeze during precool or ascent and does not foul any downstream components such as filters, etc..

Since the air supplied to the air bearing is always cold, if this cold air is supplied to the air bearing long enough when the cavity is warm and humid, the pads and structure will begin to condense moisture and freeze. Provisions should be made for supplying warm, dry air to the air bearing for ground operations.

During operation on the ground the vacuum pump serves no real purpose. In fact it is detrimental in that it uses power unnecessarily and introduces oil into the air stream. The associated refrigerator will have some small drying affect but the dryer immediately downstream of the vacuum pump will unnecessarily be removing an excessive amount of water. Assuming a typical dryer like those used presently aboard the Kuiper (RAF-BCD13X Molecular Sieve, see Appendix B) each dryer would last about 12 min. (pp. A5 - A6). This is long enough to see it through a start-up cycle but may require too frequent a change out. The control of the system should be such that the vacuum pump is prevented from operating on the ground.

It would be possible to eliminate the vacuum pump from the system altogether. The reason for having the vacuum pump is so that the air from the air bearing is not introduced into the cavity. Since the system is designed to deliver cold, dry air to the air bearing does not seem so important. Eliminating the vacuum pump would reduce the weight, space and maintenance requirements of the system as well as simplify the controls. The exhaust air need not enter the cavity however. It could be used to purge an enclosure for the bearing pads as described below and could then be vented overboard by a scavenge fan. The power required to compress cabin air from 0.6 bar to 20 bar would be approximately 7 KW (pg. A7). This is essentially the same power as that used by a compressor system utilizing a vacuum pump and a compressor but using air cooling instead of refrigeration for aftercoolers (7.3 KW, pg. A10). This system will be described in more detail below.

Another concern is the cleanliness of the bearing surface. Fig 2 shows a detail of the bearing and pads. This region is open to the cavity environment. This exposes the bearing surface to dust and moisture present in the cavity. With time this environment could cause a significant degradation of the bearing surface. Some thought should be given to better protecting this most important surface. One possibility is shown in Fig 3. A wall would be added to the cavity side of the bearing and flexible rubber diaphragms would be added to both sides of the bearing to form a sealed enclosure. A small amount of dry air from the compressor system would then be used to purge the enclosure and thus prevent contamination. A second alternative would be to add a labyrinth type seal like that used on the Kuiper.

Once the air bearing is operating at steady state, dry air recirculating through the dryers and will tend to regenerate them. At present there is no data available as to regeneration rates so no better prediction can be made as to a maintenance interval. The moisture removed from the vacuum pump dryer will be absorbed downstream by the high pressure dryers tending to reduce their lifetime. This points up the caveat mentioned earlier. During normal operation, the dry air circulating through the wet dryers will have a tendency to cause the moisture to migrate through the system. If steady operation were to continue long enough, this moisture would eventually be carried out of the dryers toward the air bearing. All of this is a function of the regeneration rate for the dryers. Therefore, care must be taken when designing the system and when choosing the maintenance interval such that the entrapped moisture can never migrate out of the dryers.

The refrigerator downstream of the high pressure compressor is to cool the exit air to 270 K, or -3 C. Since in any start-up condition the air exiting this compressor is saturated, the refrigerator will cause ice to form in the lines. Obviously this condition must be avoided.

The downstream dryers must remove the remainder of the moisture down to the minimum dew point required. The dew point needed for the proposed Zeiss system is based on the adiabatic expansion to 2.7 bar, 152 K for bearing pads 18 and 19. If an adiabatic ($PV^\gamma = c$) expansion could be achieved (see next paragraph), the dew point is calculated to be 150 K (-123 C, -190 F) at 20 bar (pp. A8 - A9). This is not readily obtainable with any convenient drying system known. The best that desiccant type dryers can obtain readily is -100 F (-73 C, 200 K). Compressing to a higher pressure helps, this is one reason the Kuiper uses 3000 psi. However, if the Zeiss system were to simply change to 3000 psi compressors the dew point required would still be 159 K (-114 C, -173 F) (pg. A10). It is better to change the expansion/cooling process.

Design of air bearing

Pressure-equalizing system

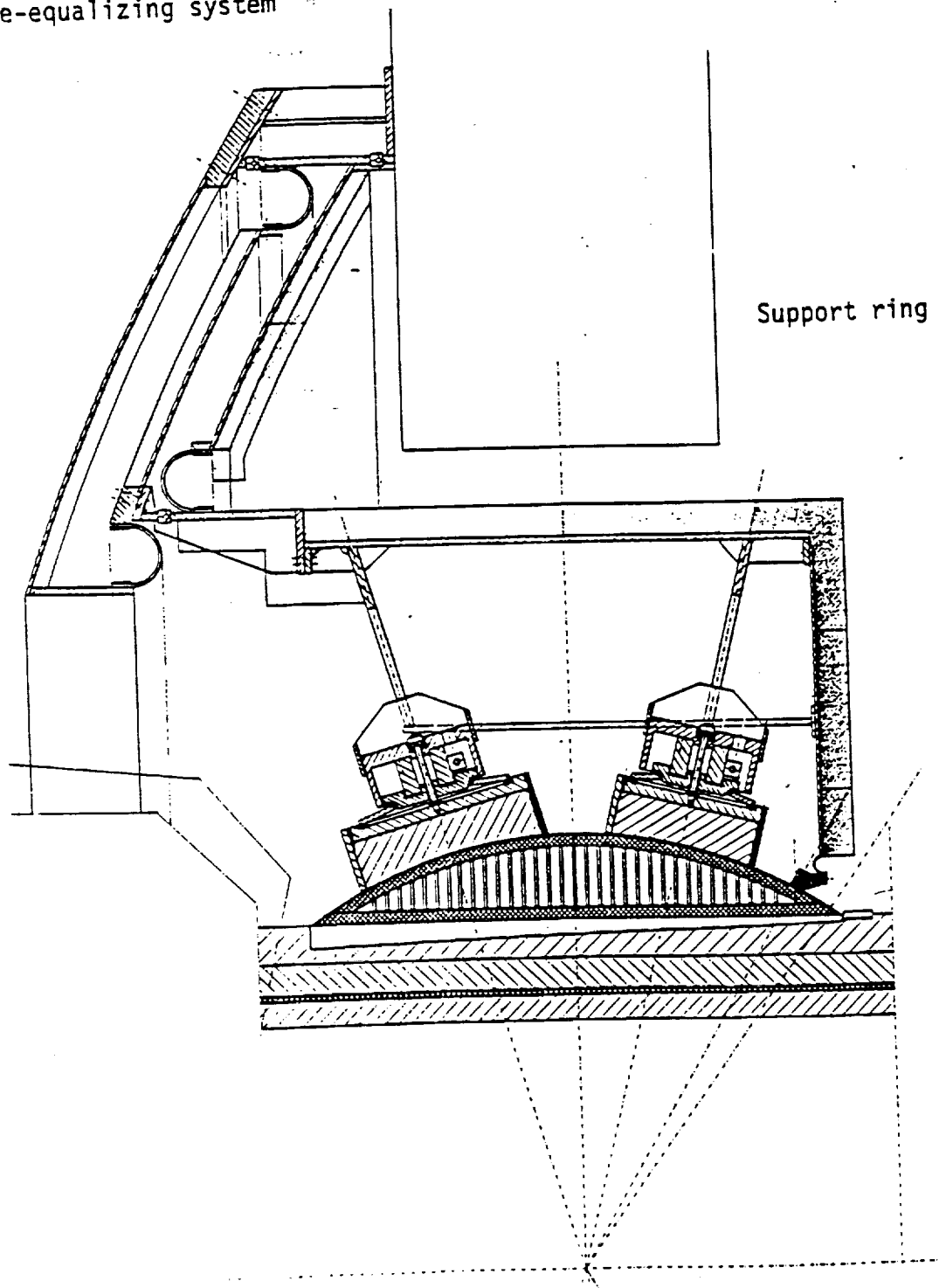


FIG 2

Design of air bearing

Pressure-equalizing system

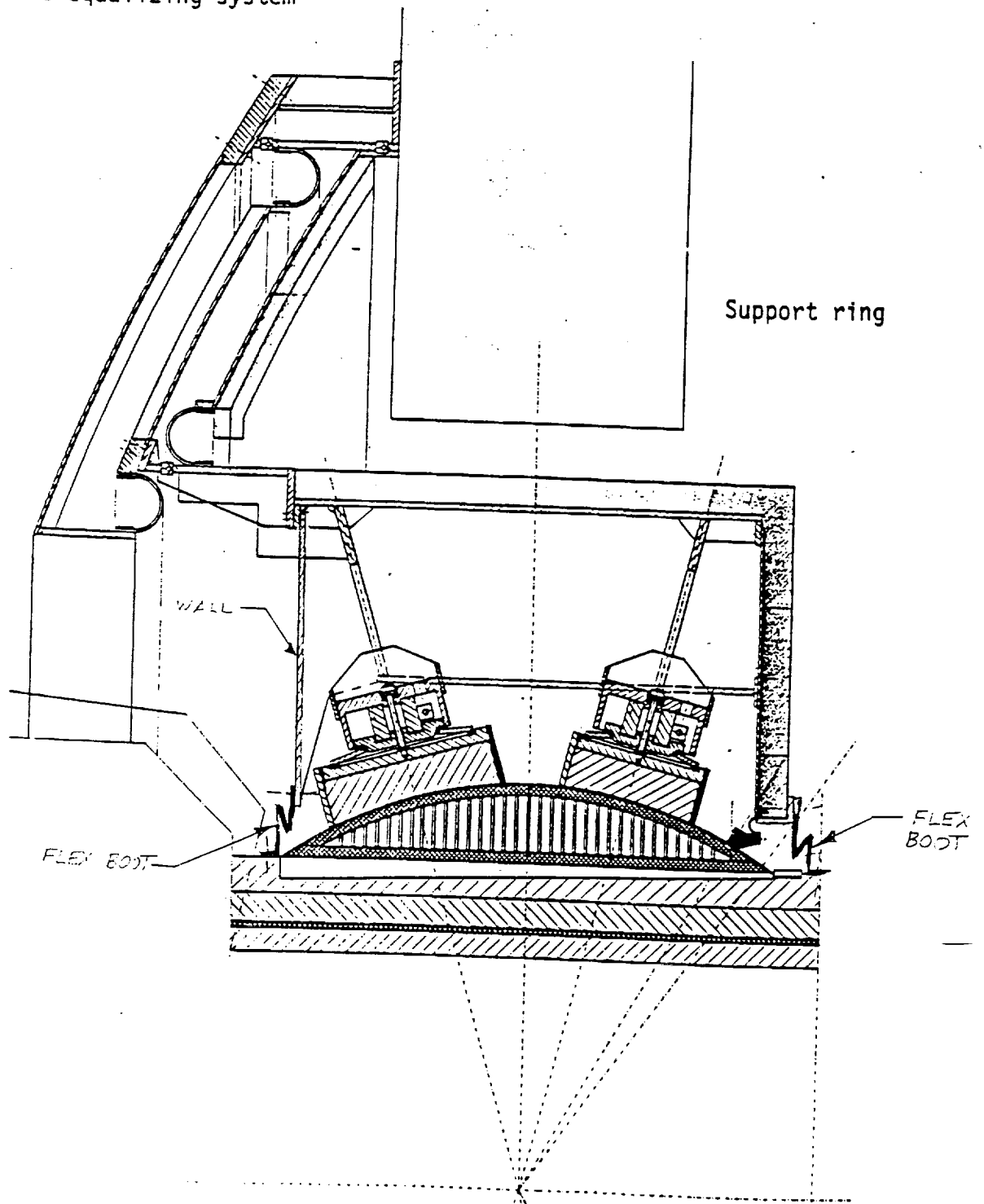


FIG 3

The most serious problem with the system is not related to moisture. It has to do with the expansion processes used to cool the air for control of the air bearing temperature. The expansion process is accomplished by restrictors which are, in essence, throttling valves. However, a throttling process is a constant enthalpy process and for an ideal gas enthalpy is a function of temperature only. That is to say, there is no temperature change of the gas during the expansion. Of course air is not an ideal gas, nevertheless the temperature of the air will not decrease substantially upon expansion through a restrictor.

Fig 4 shows a graph of the Joule-Thompson Effect for air. This shows that when air is expanded at constant enthalpy (throttled) from 20 bar (290 psia), 270 K (486 R) to 2.7 bar (39 psia), that the temperature drops to 266 K (480 R). This is a drop of only 4 K.

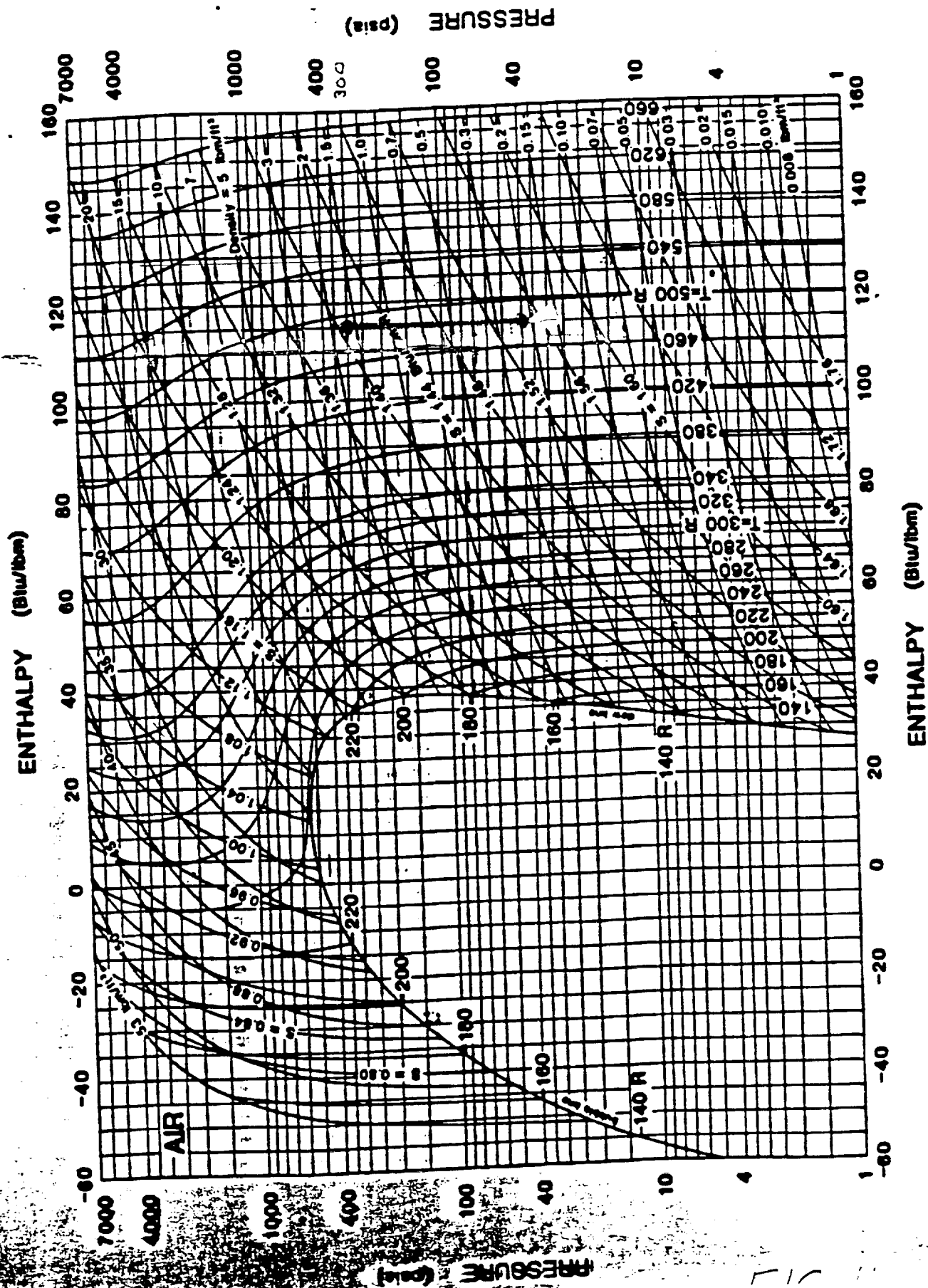
The energy equation for horizontal adiabatic flow is:

$$\Delta H + \Delta u^2 / 2g_c = W_s$$

Where:

- ΔH = Change in Enthalpy
- Δu = Change in Flow Velocity
- g_c = Proportionality Factor
- W_s = Shaft Work

From this it follows that in order to achieve a change in H (and therefore a temperature change) from the flow process, either the flow must be maintained at very high speed or work must be extracted during the process. Alternatively the flow can be throttled to the appropriate pressures for the individual pads and then refrigerated down to 215 K. (In practice the air could be refrigerated to slightly below 215 K and then reheated to 215 K at constant pressure for better temperature control). The refrigeration power required for this would be approximately 750 W for the Zeiss system and 1.5 KW (pg. A11) for the system described below.



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3000 PSI AIR THROTTLING TO 14.7 PSI
 JOULE-THOMSON EFFECT, COOLING TO NEAR 0 °F

ALTERNATE DESIGN POSSIBILITIES

Some possible refinements to the proposed system are as follows:

1. Eliminate the vacuum pump altogether, or do not run the vacuum pump on the ground. If utilized the vacuum pump should be bypassed with an interlock to the accumulator and/or switches that turn air on and off to the air bearing. If not utilized a scavenge fan will be required to vent the spent air overboard. The power required for the two systems is virtually identical but the system with no vacuum pump would be smaller, lighter and simpler.
2. Provision should be made to isolate the bearing surface from the cavity and for purging this isolated volume.
3. Do not use refrigerators at the exits from either the vacuum pump or the compressor. Ambient air will provide sufficient cooling for the system if accounted for in the design. This saves about 6 KW of required power, by Zeiss' estimates, and eliminates the possibility of ice forming in the lines.
4. An overboard dump should be provided for the moisture separators so the moisture trapped in them will not migrate into or beyond the dryers during normal operation.
5. The dryers should be designed so that water cannot migrate completely through them under any circumstances. Adequate maintenance intervals, and perhaps a moisture sensor alarm should be incorporated into the system.
6. The expansion (throttling) valves are required for pressure reduction but will not provide adequate cooling by themselves. Use a refrigerator downstream of the valves to provide the cold air for the air bearing. The refrigerator could be turned off during ground operation when the cavity is warm. The refrigerator would require about 1.5 KW of electrical power when operated. Temperature control could be provided by refrigerating the air below 215 K and using separate heaters for control back up to 215 K.
7. Provisions should be made to allow the system to run off of a ground air supply.



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Appendix A
Calculations

12,381 50 SHEETS 1 SQUARE
42,381 100 SHEETS 1 SQUARE
42,386 200 SHEETS 1 SQUARE



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Time required to purge accumulator

$$m = \frac{PV}{RT}$$

$$= \frac{19 \times 10^5 (0.18)}{287 (270)} \left(\frac{\frac{N/m^2 \cdot m^3}{kg \cdot K}}{\frac{N \cdot m}{kg \cdot K}} \right) \Rightarrow kg$$

$$m = 4.41 \text{ kg air}$$

$$t = \frac{4.41 \text{ kg}}{0.013 \text{ kg/sec}} = 339 \text{ sec} \approx 5 \frac{1}{2} \text{ min}$$

Approximate volume of remainder of system

Assume 10 tubes / moisture separator / filter
 volume of 68 in³ each 10 size
 P. moisture separator by Red Buller Division
 (see appendix E)

$$V_{\text{separator}} = 68 \text{ in}^3 = 1.11 \text{ liter}$$

Assume 500 mm 200 ft

Assume 1/4 in

$$V = \pi \left(\frac{1.25}{12} \right)^2 (200) = .074 \text{ ft}^3 = 2 \text{ liter}$$

Assume 1/8 in tubing

$$V = \pi \left(\frac{.5}{12} \right)^2 (200) = .008 \text{ ft}^3 = 6 \text{ liter}$$

Additional volume

$$V_{\text{total}} = 1.11 + 2 + 6 = 9.11 \text{ liter} \approx 10 \text{ liter} \approx 1 \text{ liter}$$

Total volume to purge

$$\frac{5.5 \text{ mm}}{100 \text{ mm}}$$

$$t_{\text{total}} = \frac{9.11}{0.013} = 700 \text{ sec}$$

$$t_{\text{total}} = \frac{700}{60} = 11.67 \text{ min}$$

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During start up, the pressure drop through the orifice at the periphery of the pad is

assume 20 mm gap height

use 5 mm gap width

Scrub to gap ratio

$$\frac{5 \times 10^{-3}}{20 \times 10^{-3}} = .25$$

assume flow in that between 2 flat plates (365 mm diameter) = 2 - 365 = 2293 mm dia. 5 mm wide a-d
.22 mm High $T = 100^\circ F = 37^\circ C$ $K = 1.4$

$$\frac{fL}{D} = \frac{5}{7} \left(\frac{1}{M_0^2} - \frac{1}{M^2} \right) + \frac{4}{7} \ln \left[\left(\frac{M_0}{M} \right)^2 \frac{M^2 + 5}{M_0^2 + 5} \right]$$

$$\text{where } V = \text{hydraulic diameter} = \frac{2A}{P} = \frac{2 \times 2293}{22 + 22} = \frac{2293(.02)}{2293}$$

$$V = .02$$

assume a friction factor of .02

$$\frac{fL}{D} = \frac{.02(5)}{.02} = 5$$

$$\frac{V_0}{V} = \frac{\dot{m}}{\rho A} = \frac{\dot{m} R T}{P A} = \frac{.001 \text{ kg/sec} (287) \frac{N}{kg \cdot m} (37)}{(1 \times 10^5) (2293) (20 \times 10^{-3})}$$

$$V_0 = 253 \text{ m/sec}$$

$$C_0 = \sqrt{1 + \frac{fL}{D}} = \sqrt{1 + 5} = (9.8) (311)$$

$$C_0 = 1100 \text{ m/sec}$$

$$\frac{1}{C_0} = \frac{1}{1100} = .0009$$

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by trial and error for $\frac{FL}{D} = 5$, $M_o = .23$

$$M = 2.976$$

$$M \approx 3.0$$

The temp drop associated with this flow would be

$$T = \frac{T_o \left[\frac{(K-1)M_o^2 + 2}{(K+1)} \right]}{(K-1)M^2 + 2} (K+1)$$

$$T = \frac{T_o [(K-1)M_o^2 + 2]}{(K-1)M^2 + 2}$$

$$T = \frac{311 [(.4)(.23)^2 + 2]}{(.4)(.3)^2 + 2}$$

$$T = 308 \text{ K}$$

$$\Delta T = 311 - 308 = 3^\circ \text{C} = 5.4^\circ \text{F}$$

The humidity ratio for 100°F air 95% R- is

$$w_{100} = .622 \frac{P_w}{P - P_w}$$

$$w_{100} = .622 \frac{.07(1.932)}{750 - 1.932}$$

$$w_{100} = 1.533 \times 10^{-3}$$

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the humidity ratio for air that I am appended and
dropped in temperature 6.0°F in

$$\omega_{94} = .622 \left(\frac{1.60^\circ}{750 - 1.60^\circ} \right)$$

$$\omega_{94} = 1,337 \times 10^{-3}$$

Since $w_{94} < w_{100}$ water will condense out in the air leaving part of water hence

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If inlet conditions for H₂ main compressor are
1 bar 245 K $T_{dp} = -100^\circ\text{F}$

$$\omega_2 = .622 \left(\frac{.0012}{750.061} \right)$$

$$\omega_2 = 9.95 \times 10^{-6}$$

main compressed to 20 bar

$$P_w \approx \frac{\omega_2}{.622} P_T$$

$$P_w \approx \frac{9.95 \times 10^{-6} (20)(750.061)}{.622}$$

$$P_w = .0240 \text{ mm Hg}$$

At a dew point of

$$\frac{1}{T} = .0045$$

$$T = 222 \text{ K}$$

$$T = -50^\circ\text{C}$$

At this condition occurs

The minimum dewpoint required for entrance to the main compressor is no ice forms upon exit

$$\omega_{270} \approx \frac{.622 P_{sat 270}}{P_{TH}}$$

$$P_{sat} = \omega_{270} P_{TH} / .622$$

$$P_{sat} = \frac{P_{sat} P_{TH}}{P_{TH}} = \frac{4.21 \times 10^{-4}}{20} = .21 \times 10^{-4}$$

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The driver must remove the following water during startup

$$w_{-32} = .622 \left(\frac{.21}{750.061} \right)$$

$$w_{-32} = 1.74 \times 10^{-4}$$

$$w_{\text{atm}} = \frac{.95(48.8)(.622)}{750.061}$$

$$w_{\text{atm}} = .038$$

$$\Delta w = w_{\text{atm}} - w_{-32} = .038 - .0002$$

$$\Delta w \approx .038 \quad \begin{array}{l} \text{lb. water} \\ \text{lb. air} \end{array}$$

for the flow rate used on SOFIA

$$\Delta m = .038 (.078) (5.16)$$

$$\Delta m = .015 \frac{\text{lb. water}}{\text{min}}$$

assuming driver will absorb the equivalent amount to
have occurred previously

$$T = \frac{.74(1.2)}{.015} = 12 \text{ min}$$

Power required to compress the air from cabin pressure (1.6 bar) to 20 bar directly - ie no vacuum pump
 Assume 100°F (38°C 311°K) day

$$P = \frac{\gamma}{\gamma-1} \cdot \dot{m} \cdot R \cdot T_1 \cdot \left[\left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]$$

$$P = \frac{1.4}{.4} \cdot (.013) (287) (311) \left[\left(\frac{20}{.6} \right)^{\frac{.4}{1.4}} - 1 \right]$$

$$P = 7000 \text{ W}$$

$$P = 7 \text{ KW}$$

the power required by the vacuum pump and compressor together for a system that uses a vacuum pump to compress from 2 bar 215 K to 1 bar 323 K (using air cooling) and then a compressor to go from 1 bar 323 K to 20 bar is found on page A 13

$$P_c = 5.7 \text{ KW}$$

$$P_v = 1.6 \text{ KW}$$

$$\text{Total } P_{\text{comp}} = 7.3 \text{ KW}$$

TITLE _____

20 bar (Zeiss) System

humidity ratio required.

For worst case of $P = 2.7 \text{ bar}$ $T = 152 \text{ K}$ in
 pads 18 + 19 (use dew point of 10°K below max line
 temp $T_{dp142} = 142 \text{ K}$)

$$\omega = \frac{m_w}{m_a} = .622 \frac{P_w}{P_T - P_w}$$

- ME Review Manual
 5th Ed. Michael
 Lindenberg

$$P_T = 2.7 (\text{bar}) \frac{750.061 (\text{mm Hg})}{\text{bar}}$$

$$P_T = 2025.16 \text{ mm Hg}$$

$$P_w = 4.12 \times 10^{-9} (\text{mm Hg})$$

- from graph of
 log P vs T of data
 in CRC Handbook of
 Chemistry and Physics

$$\omega = .622 \left(\frac{4.12 \times 10^{-9}}{2025 - 0} \right)$$

$$\omega = 1.265 \times 10^{-12} \frac{\text{lb}_w}{\text{lb}_m}$$

Assume exit conditions from the compression of 20 bar
 and $T = 274^\circ \text{K}$ (just above freezing). If air
 with ω as above were compressed to 20 bar 274°K
 the dew point temp would be as follows

$$\omega = .622 \frac{P_w}{P_T - P_w}$$

$$\omega P_T - \omega P_w = .622 P_w$$

$$\omega P_T = (.622 + \omega) P_w$$

$$P_w = \frac{\omega P_T}{.622 + \omega} \approx \frac{\omega P_T}{.622}$$

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20 bar (Zeiss) System (Cont)

$$P_w = \frac{1.265 \times 10^{-12} (20)}{.622}$$

$$P_w = 4.067 \times 10^{-11} \text{ bar } (750.061) \left(\frac{\text{mm Hg}}{\text{bar}} \right)$$

$$P_w = 3.050 \times 10^{-8} \text{ mm Hg}$$

$$\frac{1}{T} \approx .00668$$

$$T_{dp} \approx 150 \text{ K } (-123^\circ \text{C}) (-190^\circ \text{F})$$

This is not readily attainable with chemical/desiccant driers.
The mass of water the drier must remove is found
as follows (Compression exit conditions 20 bar, 274 K)

$$P_{\text{sat } 274 \text{ K}} = 4.926 \text{ mm Hg}$$

$$\omega_{274} = .622 \frac{4.926}{20(750.061) - 4.926}$$

$$\omega_{274} = 2.04 \times 10^{-4}$$

$$\Delta \omega = \omega_{274} - \omega_{142} = 2.04 \times 10^{-4} - 1.26 \times 10^{-12}$$

$$\Delta \omega \approx 2.04 \times 10^{-4} \frac{\text{lb}_m \text{ water}}{\text{lb}_m \text{ air}}$$

$$\Delta \omega \approx 2.04 \times 10^{-4} \left(\frac{\text{lb}_m \text{ water}}{\text{lb}_m \text{ air}} \right) \left(.078 \frac{\text{lb}_m \text{ air}}{\text{SCF air}} \right)$$

$$\Delta \omega = 1.59 \times 10^{-5} \frac{\text{lb}_m \text{ water}}{\text{SCF air}}$$

$$\text{mass flow rate of } 30.1 \times 10^{-4} \text{ kg/sec} = 5.16 \text{ SCFM}$$

$$\Delta \omega = 1.59 \times 10^{-5} (5.6)$$

$$\Delta \omega = 8.90 \times 10^{-5} \frac{\text{lb}_m \text{ water}}{\text{SCF air}}$$

TITLE

3000 psi system

If air with $\omega_{1,42} = 1.265 \times 10^{-12}$ were compressed to 3000 psia = 207 bar $t_{1,42}$ dew point temp needed would be

$$P_w \approx \frac{\omega P_T}{.622}$$

$$P_w \approx \frac{1.265 \times 10^{-12} (207)(750.061)}{.622}$$

$$P_w \approx 3,16 \times 10^{-7} \text{ mm Hg}$$

$$1/T_{dp} = .00630$$

$$T_2 = 159 \text{ K} \quad (-114^\circ \text{C}) \quad (-173^\circ \text{F})$$

This is not readily obtainable with General Purpose 2-2-

The mass of water the driver must remove is found as follows (compression exit conditions 207 bar, 50°C (323 K)) (ground speed 100 km/h - air temp 100°F compression exit 120°F)

$$P_{\text{sat } 323^\circ\text{C}} = 92,51 \text{ mm Hg}$$

$$\omega_{323} = .622 \frac{P_u}{P_T - P_u}$$

$$w = .622 \frac{92.51}{207(750.061) - 92.51}$$

$$\omega_{323} = 5.96 \times 10^{-4} \text{ lb-}/\text{lb}_m$$

$$u_{342} - u_{142} = 5.96 \times 10^{-4} - 1.265 \times 10^{-12}$$

$$\omega \approx 5.26 \times 10^{-7} \frac{16 \text{ m water}}{16 \text{ m air}}$$

5.16 SCFM

$$-n = 5.16 \times 10^{-2} \times \frac{10^{-2} \text{ m}}{10^{-2} \text{ m}} \times 0.2 \times \frac{10^{-2} \text{ m}}{10^{-2} \text{ m}} \times 5.16 \frac{\text{C}}{\text{F}}$$

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Refrigeration Power required for compressor outlet
(before drier)

$$W = \frac{Q}{w} \quad \Rightarrow \quad P = \frac{\dot{Q}}{w}$$

w = coefficient of performance

Q = heat extracted

$$\dot{Q} = \dot{m} c_p (T_2 - T_1)$$

$$\dot{m} = .013 \text{ kg/sec}$$

$$T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} = 245 \left(\frac{20}{1} \right)^{\frac{1.4}{1.4}} = 576 \text{ } ^\circ\text{K}$$

$$c_p = 1047 \frac{\text{J}}{\text{kg K}}$$

$$\dot{Q} = .013 (1047) (576 - 270)$$

$$\dot{Q} = 4119 \text{ J/sec}$$

$$\dot{Q} = 4.12 \text{ kW}$$

Since the coefficient of performance $w = 1$ (low for a refrigerator) the power required is within the range stated by Jones.

Refrigeration required for cooling air to airbearing temp.

$$\dot{Q} = \dot{m} c_p (T_2 - T_1)$$

$$\dot{Q} = .013 (1047) (270 - 215)$$

$$\dot{Q} = 748 \text{ W}$$

Now assume coefficient of performance of 1 (worst case)
W. work required is also 750 W

Assume air temp. of 323 K (for revised system calculation)

$$\dot{Q} = .013 (1047) (323 - 215)$$

$$\dot{Q} = 1151 \text{ W}$$

TITLE _____

Filter Requirements

The smallest jet cross sectional area is:

$$A = .39 \times 10^{-7} \text{ m}^2$$

for pads 18 and 19 (Telescope system final report)
section 4.2.2.2 pg 12

This implies an dia of

$$A = \frac{\pi d^2}{4}$$

$$d = \sqrt{\frac{4A}{\pi}}$$

$$d = \sqrt{\frac{4(.39 \times 10^{-7})}{\pi}}$$

$$d = 2.23 \times 10^{-4} \text{ m}$$

$$d = .22 \text{ mm } (.0088 \text{ in})$$

The air gaps in the bearings are nominal, 10 microns - and may close to 8 microns under load

Robinson aviation provides filters that remove particles down to .3 microns. Ratio of gap size to particle size

$$8/.3 = 26$$

A ratio of gap size to particle size of 15 would probably be adequate

$$\text{Filter requirement } \frac{8}{15} \approx .5$$

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Power requirements for compressor

assuming adiabatic compression from 50°C (122°F)
on ground

$$P = \frac{\gamma}{\gamma - 1} \cdot \dot{m} \cdot R \cdot T \left[\left(\frac{P_2}{P_1} \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right]$$

$$P = \frac{1.4}{.4} (.013)(287)(323) \left[\left(\frac{20}{1} \right)^{\frac{.4}{1.4}} - 1 \right]$$

$$P = 5709 \text{ W}$$

$$P = 5.7 \text{ kW}$$

Vacuum Pump Power = 1.64 kW (from Zelen)

Total compressor power

$$5.7 + 1.64 = 7.34 \text{ kW}$$

Heater power required

assume the air is cooled to 211K by the refrigerator

$$\dot{Q} = .013(1047)4$$

$$\dot{Q} = 54 \text{ W}$$

Accumulator size (assume 323 K ambient temp)
using 3 min operation 10 bar max pressure (from Zelen)

$$V = \frac{\dot{m} \Delta T \cdot R \cdot T}{\Delta P}$$

$$V = \frac{.013(180)(287)(323)}{10^5}$$

$$V = 125 \text{ m}^3 = 220 \text{ liters}$$

TITLE

Dew point requirement

the worst case dew point requirement will be for 2.7 bar 211 K for pads 18 and 19. If 203 K is used to provide some safety factor on the dewpoint, the dewpoint at the higher pressure is found as follows

$$w_{200} = .622 \frac{P_w}{P_T}$$

$$w_{200} = .622 \frac{.00194}{2.7(750.061)}$$

$$w_{200} = 5.96 \times 10^{-7} \frac{16 \text{ water}}{16 \text{ air}}$$

at the higher pressure

$$P_w = \frac{w_{200} P_T}{.622}$$

$$P_w = \frac{5.96 \times 10^{-7} (20)(750.061)}{.622}$$

$$P_w = .0144 \text{ mm Hg}$$

$$T_{dp} = -52^\circ \text{C}$$

based on refrigeration

TITLE _____

NAME _____ CODE _____

CH'KD BY _____ DATE _____

Downstream temperature for isentropic expansion through converging
diverging nozzle with subsequent
compression through a shock wave

$$\frac{P_2}{P_1} = \frac{2KM_1^2 - (K-1)}{K+1}$$

$$\frac{P_0}{P_1} = \left(1 + \frac{K-1}{2} M_1^2\right)^{\frac{K}{K-1}}$$

$$\frac{P_2}{P_0} = \frac{2KM_1^2 - (K-1)}{(K+1)\left(1 + \frac{K-1}{2} M_1^2\right)^{\frac{K}{K-1}}}$$

$$P_2 = 2.7 \text{ bar}$$

$$P_0 = 20 \text{ bar}$$

$$P_2/P_0 = .135$$

$$M_1 = 3.88$$

$$P_1 = \frac{P_0}{\left(1 + \frac{K-1}{2} M_1^2\right)^{\frac{K}{K-1}}} = \frac{20}{\left[1 + \frac{.4}{2} (3.88)^2\right]^{1.4}} = \frac{20}{(4.011)^{1.4}}$$

$$P_1 = \frac{20}{129} = .155 \text{ bar}$$

$$T_1 = \frac{T_0}{1 + \frac{K-1}{2} M_1^2} = \frac{293}{4.011}$$

$$T_1 = 73 \text{ K}$$

This low point would be extremely difficult to achieve.

TITLE _____

$$\frac{P_2}{P_1} = \frac{1 + K M_1^2}{1 + K M_2^2}$$

$$1 + K M_2^2 = (1 + K M_1^2) \left(\frac{P_1}{P_2} \right)$$

$$M_2^2 = \frac{(1 + K M_1^2) \frac{P_1}{P_2} - 1}{K}$$

$$M_2^2 = \frac{(1 + 1.4(3.88)^2) \left(\frac{0.155}{2.7} \right) - 1}{1.4}$$

$$M_2^2 = .191$$

$$M_2 = .437$$

$$T_2 = T_1 \left[\frac{1 + \frac{K-1}{2} M_1^2}{1 + \frac{K-1}{2} M_2^2} \right]$$

$$T_2 = 73 \left[\frac{1 + \frac{.4}{2} (3.88)^2}{1 + \frac{.4}{2} (.437)^2} \right]$$

$$T_2 = 73 (3.863)$$

$$T_2 = 282 \text{ K}$$



Ames Research
Center

SYSTEMS
ENGINEERING DIVISION

EE

DOCUMENT No.

DATE _____ PAGE _____ of _____

TITLE _____

NAME _____ CODE _____

CH'KD BY _____ DATE _____

Appendix B

Dryer Data Sheets

42 381 10 SHEETS 1 SQUARE
42 382 100 SHEETS 1 SQUARE
42 383 200 SHEETS 1 SQUARE



DESCRIPTIVE, ORDERING, INSTALLATION, AND MAINTENANCE INFORMATION



PURIFIER CHAMBERS

RAF® Purifier Chambers are pressure vessels designed for use with a companion RAF® Purifier Cartridge to remove water, oil vapors, and gaseous contaminants from pressurized air or gases — such as oxygen, nitrogen, hydrogen, helium, argon, etc.

RAF® Purifier Chambers, together with RAF® Mechanical Filters, are the major components of RAF® Purification Systems. The Chambers are installed in the flow path downstream of the Mechanical Filter, whose function it is to remove solid particles and liquid contaminants, thus lessening the load on the downstream Purifier Cartridges and increasing their efficiency and life span.

Single Purifier Chambers, with an appropriate Cartridge, also have a number of other uses:

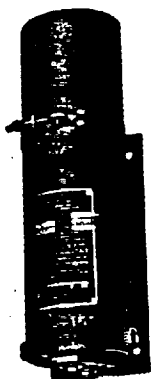
- Downstream of an RAF® Purification System when an especially low moisture content is desired — particularly in the case of Systems utilizing a Cartridge containing a catalyst for carbon monoxide elimination.
- Close to the point of usage as a "booster" purifier station in a long supply line following an RAF® Purification System. Depending on line length, more than one such secondary purifier may be necessary.
- For additional purification of dry commercial-grade gases, such as nitrogen. More than one Chamber may be needed to achieve required purity levels.

Single Purifier Chambers, without Cartridge, are also ideal for use as small high pressure receivers.

RAF® Purifier Chambers have been designed with special emphasis on the elimination of blind cavities that might entrap impurities. A unique feature is the single balanced-pressure O-ring that provides a bypass-proof seal between the Chamber and the Cartridge at the inlet, and prevents contaminants from going downstream or being deposited on the Chamber walls. The Chambers are designed to conform to the ASME Code for Unfired Pressure Vessels even though, because they are less than six inches in diameter, they do not fall within the Code's jurisdiction.

RAF® Purifier Chambers are available in several pressure ratings and in two lengths; some models are aluminum, while others are steel alloy (see Table II). The aluminum models, because of their light weight and corrosion resistance, are especially well suited for airborne and marine use, or other applications in which either or both of these factors are important considerations.

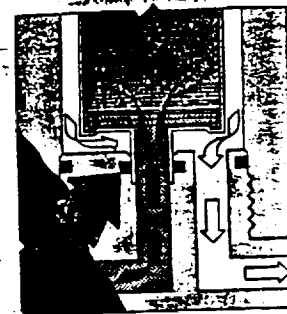
TYPICAL MODELS



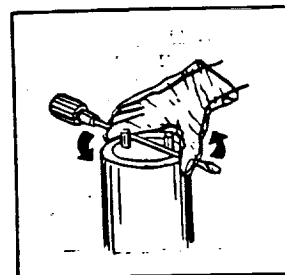
RAF-4B



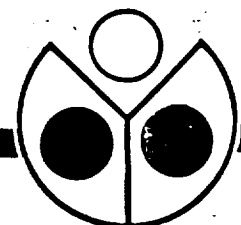
RAF-6ASP



Leakproof trouble-free operation



Ease of maintenance—no special tools



PURIFIER CARTRIDGES

RAF® Purifier Cartridges are the functional components used in RAF® Purifier Chambers. The Cartridges are constructed of specially milled hot dip tinplate (MRT-3), and contain one or more active materials, each of which effects a special kind or degree of purification.

Cartridge efficiency and capacity is dependent upon a number of variables such as contaminant concentration in the input air or gas, regularity and quality of maintenance, and operating conditions such as pressure, temperature, and flow rate. Higher pressures and/or lower temperatures prolong cartridge life, while lower pressures and/or high temperatures reduce it (see Table VI). Similarly, slower flow rates contribute to cartridge life and efficiency by permitting a longer "dwell time" of the fluid medium through the adsorbent bed. Thus maximum efficiency is achieved when flow rate is no greater than 20 SCFM.

Cartridges come in two sizes (though not all models are available in both sizes): "B" size (short) for use in "B" size Purifier Chambers, and "SP" size (long) for use in "SP" size Purifier Chambers.

Major characteristics and usage of the various RAF® Purifier Cartridges are as follows:

Type 13X Cartridges strongly adsorb most of the contaminants commonly present in air and inert gases. Thus, these Cartridges are capable of reducing moisture content to a —100°F dewpoint, and simultaneously capable of removing gaseous hydrocarbons to less than 1 PPM/w (hexane equivalent) and most common noxious gases (except carbon monoxide) to levels undetectable by practical means.

Charcoal Cartridges contain a high grade of activated carbon and are primarily used for odor removal, though they are also effective in adsorbing oil vapors and a number of other contaminants.

Between them, Type 13X and Charcoal Cartridges remove not only the contaminants already mentioned, but are also effective in removing most organic vapors and many inorganic compounds. They are highly effective in removing acrylonitrile, vinyl chloride, halogenated solvents, nitrogen oxides, and sulfur compounds — all of which present a serious health hazard in respiratory air, and some of which are recognized carcinogens. Both the above Cartridges come in "B" and "SP" sizes.

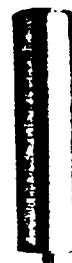
Catalyst Cartridges are available in "B" size only and are used in Series 8197 RAF® Respiratory Systems. These Cartridges contain a granular mixture of specially prepared oxides, which are highly

(Continued on Page 2)

RAF-BCO



RAF-BCD()



RAF-SPT()



CARTRIDGE INSTALLATION AND REPLACEMENT

A Purifier Chamber must never be put in service without first having a Purifier Cartridge installed in it. An initial Cartridge is always supplied with Purifier Towers, and an initial set of Cartridges is supplied with Purification Systems.

All RAF® Cartridges are of the disposable type and must be replaced before they are spent. Operating with a spent (ineffective) Cartridge will result in contamination of the Chambers, of the lines, and of the equipment downstream. If the medium is air intended for human respiration, the results can be not only serious but fatal.

Because of the many variables involved, it is impossible to estimate Cartridge life accurately. For this reason a color-change Moisture Indicator is available for determining the approximate degree of Cartridge saturation while the system is in operation. A Data Sheet on this instrument is available upon request.

Cartridges come individually sealed in special polyethylene bags, which not only keep the Cartridges dry and clean until just before use, but also make it possible to handle the Cartridge through the bag during installation, thus preventing possible contamination from the operator's hands.

The sealed Cartridges should be visually inspected before installation; broken seals indicate possible contamination and premature exposure to moisture. Cartridges containing molecular sieves are vacuum-sealed and may go "out of round" if roughly handled during shipment. Acceptable roundness usually returns when the Tube Seal Cap is removed just prior to installation. Refer to the Acceptable Roundness specification on this page.

Cartridge replacement is quickly and easily accomplished without special tools. Step-by-step instructions for replacement of both "B" size and "SP" size Cartridges are given on this page and on the nameplate affixed to each Purifier Chamber itself.

When replacing Cartridges in a Purification System, all the Cartridges in the System should be replaced at the same time; the Indicator Capsule in the Moisture Indicator should be replaced at that time also.

INSTRUCTIONS FOR INSTALLING RAF PURIFIER CARTRIDGES IN RAF PURIFIER CHAMBERS

IMPORTANT: EXTREME CLEANLINESS AT EVERY STEP OF CARTRIDGE REPLACEMENT IS ESSENTIAL.
A little extra care in this regard will enhance performance and reduce maintenance.

COMPLETE CARTRIDGE REPLACEMENT IN ONE PURIFIER CHAMBER BEFORE PROCEEDING TO THE NEXT.
This will reduce possibility of contamination and ensure that Body or Plug is reinstalled on the same Chamber from which it was removed, as main assembly parts are NOT interchangeable.

"B" SIZE

(Approx. 10 inches long)

1. RELEASE PRESSURE SLOWLY TO PREVENT CONDENSATION ON INTERIOR OF CHAMBER (see Note). DEPENDING ON RELATIVE HUMIDITY OF ATMOSPHERE, ALLOW 15 MINUTES TO ONE HOUR AFTER BLEEDING SYSTEM SLOWLY DOWN TO ZERO PRESSURE BEFORE OPENING CHAMBER FOR CARTRIDGE REPLACEMENT.
2. Wipe off top of Chamber with clean lint-free cloth.
3. Unlock Retainer Clamp (A) and unscrew Purifier Chamber Body from Chamber Head, using a strap wrench if necessary. Set Body aside on a clean surface. Remove and discard spent Cartridge.
4. Lubricate lightly Plug O-rings and threads with an inert lubricant.*
5. WHILE HANDLING CARTRIDGE THROUGH BAG SO AS TO PREVENT HAND CONTACT:
 - a. Open bag at both ends.
 - b. Using a clean sharp knife, lift end of sealing tape that covers exhaust holes on all Cartridges (except RAF-BCO Filter Cartridge). Pull off and discard the tape.
 - c. Similarly remove Seal Cap from Cartridge Tube (R).
 - d. Lubricate* Cartridge Tube lightly.
 - e. Still holding Cartridge through bag, insert Cartridge Tube (R) in center opening at Chamber Head until it is securely seated in the O-ring. Rotate Cartridge slightly in both directions to effect a seal between the Tube and the O-ring. Remove and discard plastic bag.
6. Slide Chamber Body over Cartridge and screw it on to Chamber Head as far as it will go; then back off until index lines (E) match. DO NOT TIGHTEN BEYOND THIS POINT.
7. Close and lock Retainer Clamp.
8. PRESSURIZE SLOWLY. High pressure surge will damage Cartridge.



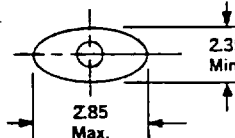
"SP" SIZE

(Approx. 25 inches long)

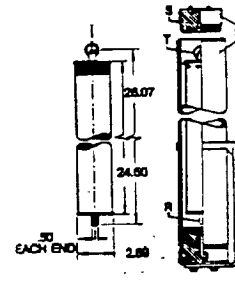
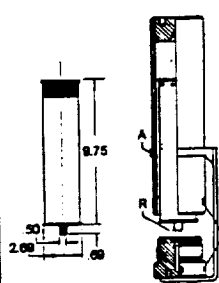
1. RELEASE PRESSURE SLOWLY TO PREVENT CONDENSATION ON INTERIOR OF CHAMBER (see Note). DEPENDING ON RELATIVE HUMIDITY OF ATMOSPHERE, ALLOW 15 MINUTES TO ONE HOUR AFTER BLEEDING SYSTEM SLOWLY DOWN TO ZERO PRESSURE BEFORE OPENING CHAMBER FOR CARTRIDGE REPLACEMENT.
2. Wipe off top of Chamber with clean lint-free cloth.
3. Unscrew Plug (S) from Purifier Chamber body, setting it aside on a clean surface.
4. Rotate spent Cartridge slightly in both directions to break the seal between the Cartridge Tube (R) and the Chamber O-ring. Using Extractor Ring (T), pull spent Cartridge straight up and discard it.
5. Lubricate lightly Plug O-rings and threads with an inert lubricant.*
6. WHILE HANDLING CARTRIDGE THROUGH BAG SO AS TO PREVENT HAND CONTACT:
 - a. Open bag at both ends.
 - b. Using a clean sharp knife, lift end of sealing tape that covers exhaust holes. Pull off and discard the tape.
 - c. Similarly remove Seal Cap from Cartridge Tube (R) and discard it.
 - d. Lubricate* Cartridge Tube lightly.
 - e. Holding Cartridge by Extractor Ring (but still through bag), insert Cartridge into Chamber Body until Cartridge Tube (R) is securely seated in O-ring at Chamber Head. Rotate Cartridge slightly in both directions to effect a seal between the Tube and the O-ring. Discard plastic bag.
7. Screw Plug into Chamber Body as far as it will go; then back off until index lines (E) match. DO NOT TIGHTEN BEYOND THIS POINT.
8. PRESSURIZE SLOWLY. High pressure surge will damage Cartridge.

* Halocarbon 25-55 is used at the factory.
Lubricant must be clean and free from contamination.

ACCEPTABLE
ROUNDNESS
SPECIFICATION
for Type 13X
and Combinations
1, 2 & 4 Cartridges,
which are vacuum-
sealed.



Note: Condensation of moist air on interior surfaces of the Chamber introduces needless contamination and may also reduce the effectiveness of newly installed Cartridge.



DYNATECH FRONTIER CORP.

Valves and
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